Hitotsubashi Journal of Economics 27 (1986) 1-10. © The Hitotsubashi Academy

TECHNICAL PROGRESS IN SILK INDUSTRY IN PREWAR JAPAN*
—THE TYPES OF BORROWED TECHNOLOGY—

AKIRA ONO

The growth of the Japanese silk industry before World War II depended heavily on two factors. The first was a demand for Japanese silk from abroad (but this is not an aspect of the problem discussed here), and the second factor was the conditions on the supply side; especially technical progress which contributed to both the rise in labor productivity and the improvement in the quality of silk. The technical progress in the silk industry involved a number of innovations, most of which were of a small scale, and with the exception of some machine filatures in the beginning of Meiji, were developed by the silk manufacturers for themselves. The increase in silk output required a greater amount of cocoons. The continuously rising demand for cocoons was met by the expansion of mulberry fields and the change in the method of cocoon production. There were also many innovations in sericulture, and some important examples of them will be shown, though most part of our investigation is confined to the silk reeling process.

This paper attempts to throw some lights on the characteristics of technical progress in the silk industry. In the following sections, we will evaluate the importance of small innovations (Section I), point out two typical cases of borrowed technology (Section II), and lastly measure the rate of technical progress in machine filatures (Section III).

I. *Importance of Small Innovations*

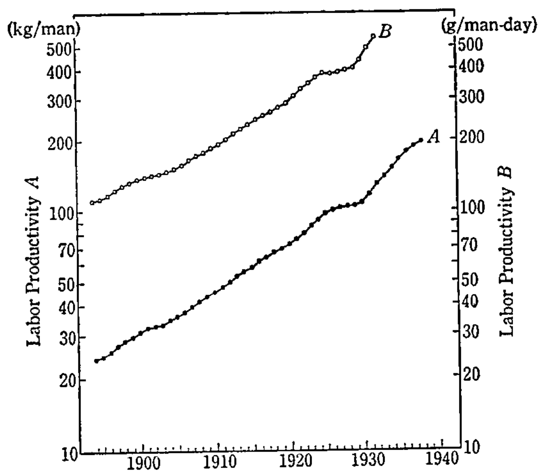
Silk output consists mainly of *Zakuri* silk and machine reeled silk. *Zakuri* silk is that produced with the primitive wooden reeling equipments inherited from the Tokugawa era, and was widely spread in the early Meiji period. Beginning with the opening of the ports, more elaborate reeling equipments made of iron were imported from Europe. A more advanced reeling technique embodied in these imported equipments stimulated the Japanese silk industry to improve the method of production, and gave rise to machine filatures as against *Zakuri* establishments. *Zakuri* silk was the major part of silk output in the beginning of the Meiji era, but soon it lost ground to machine reeled silk. In 1894 the share of *Zakuri* silk in the total output dropped to less than half, and thereafter machine reeled silk dominated both silk production and its exportation.

The labor productivity in the silk industr y was almost continuously rising. In Figure 1,

---

* This is an abridged translation of my Japanese paper, "Gijutsu Shinpo to Borrowed Technology no Ruikei" in J. Tsukui and Y. Murakami, eds., *Keizai Seicho Riron no Tenbo* (*Survey of the Theories of Economic Growth*), Iwanami Shoten, 1968. It is Professor Ippei Yamazawa who suggested to me that this paper be translated. Much thanks are due to Mr. S. Goods for his editing the English.

FIGURE 1. THE TRENDS OF LABOR PRODUCTIVITY IN MACHINE FILATURES



Note: The number of days of factory operation were taken from Dainihon Sanshikai Shinano Shikai, *Shinano Sanshigyō Shi* (*The History of Sericulture and Filature in Nagano Prefecture*), 1937, Vol. 3. The output and the number of female operatives were estimated by the author. See S. Fujino, S. Fujino, and A. Ono, *Textiles*, 1979, Toyo Keizai Shinposha (K. Ohkawa *et al.*, eds.), *Estimates of Long-Term Economic Statistics of Japan Since* 1868, Vol. 11).

two series of labor productivity for machine filatures are drawn in five year moving averages; the series A is output per female operative, and B is daily output per female operative. During the overlapping years 1894 to 1932, the series A grew from 24 Kg to 130 Kg, and the series B from 111 g to 545 g. Both increased about five times as large as their initial levels. As for *Zakuri* establishments, the rising labor productivity can also be observed. They raised their output per female operative from 12 Kg in 1896 to 29 Kg in 1937. The increase in labor productivity is associated with the increase in capital intensity, the latter being, in the case of silk industry, closely related to the number of reels equipped with one reeling basin. The more reels are equipped, the more silk threads is one reeling operative able to deal with. Under given technological knowledge, however, the increase in reels per basin requires the operative to slow down the speed of reeling, because it takes more time for her to find the filament ends and join them to the moving threads.[1] Therefore, the growth of labor productivity attained by the increase in reels per basin would be limited if there is no technical progress.

Spectacular innovations, such as changes in power sources, applications of electronical invention, and appearance of new synthetics, very often attract public attention, and, in fact, many industries owe very much to these outstanding innovations for shifting production

[1] In 1926, the standard number of rotations of reels per minute was as follows;

In case of basin with	three reels	350–400
	four reels	300–350
	five reels	250–300
	six reels	about 250

These figures are from Dainihon Sanshikai, *Nihon Sanshigyō Shi* (*History of Sericulture and Filature in Japan*), 1935, Vol. 2, Part of the History of Silk Reeling, p. 363.

functions upward and raising the rate of return on capital. It is needless to say that we received several noteworthy technical stimuli in the sericulture and filature. These examples are the introduction of iron reeling equipments in the beginning of Meiji, the discovery of the first filial generation of silkworm in the latter half of 1910's, and for the postwar period, the completion of automatic silk reeling machines. These outstanding innovations are however intermittent in nature, while the rise in labor productivity is almost continuous. From looking at the continuously rising labor productivity, part of which can be attributed to the diffusion of spectacular innovations among entrepreneurs, we can see that the great number of small devices are also important. The silk reeling process consists of several steps, that is, drying cocoons, boiling them, finding filament ends, and binding the filaments of several cocoons together. The operative must stop the reel if a filament ends or is broken, and join a new filament to the thread. Minute technical devices for each step of the reeling process would have, when continuously introduced, made a remarkable influence on productive efficiency.

In order to squeeze the water from the thread and bind the filaments together, most of the Japanese entrepreneurs adopted the Kennel system, in which the thread is looped back and twisted around itself via a set of small pulleys. In this system the location of pulleys makes a difference to the tension of the thread. If the thread is pulled strongly, it will often break and the amount of silk produced per hour will decrease. The reeling method called *Inazuma* was one of the devices for reducing the tension, in which the pulleys were relocated lest a strong pull be applied to the thread, so that this method was suited for making silk in the day when the cocoons were generally inferior in quality. The materials of which pulleys are made (wood, aluminum, and both wood and aluminum) are also related to the reeling efficiency. Some experiments showed that the pulley made of aluminum whirls most smoothly and helps to increase the output per hour. In the case where each basin has many reels, labor productivity can be raised by installing the stopping and the jointing implements. The former is for stopping not all reels but only the reel whose thread broke. The latter is the implement which mechanized the jointing of a filament that was previously committed wholly to the operative's fingers.

The drying of cocoons resulted in their filaments being reeled more smoothly as well as the ability to store them for several months.[2] The entrepreneurs learned, either by experience or by experiments, at what temperature and to what extent the cocoons should be dried. The method of boiling also advanced. Instead of boiling cocoons at a constant temperature from beginning to end, they adopted the different method in which the water temperature was kept low at first and then gradually raised, with the result that the outer and the inner part of cocoons were uniformly boiled. In 1920's the production process in almost all machine filatures was divided into two stages, that is boiling and reeling; both of which had been performed at the same time by a single operator. From this division of labor, we can expect the advantages of specialization. The innovations in sericulture, though this is not a technical progress in reeling process itself, made it possible to produce cocoons whose filaments could be easily reeled off, and thus this contributed to the rise in labor productivity. The change in the quality of cocoons was brought about by the government's regulations on silkworm eggs, the advance in the method of silkworm breeding, or by the discovery of the

[2] Together with the development of so-called summer and autumn cocoons, the drying excluded the seasonality from the raw silk industry.

TABLE 1. TRANSITION MATRIX OF MACHINE FILATURES BY SCALE, FACTORIES WITH MORE THAN TEN REELING BASINS, NAGANO PREFECTURE

July 1911 \ May 1918	10 ~ 49	50 ~ 99	100 ~ 149	150 ~ 199	200 ~ 249	250 ~ 299	300 ~ 349	350 ~ 399	400 ~ 449	450 ~ 499	500 ~ 599	600 ~ 699	700 ~ 799	800 ~ 899	900 ~ 999	1000 ~	Sub total	Withdrawal	Total
10~ 49	76	33	6	2													117	115	232
50~ 99	6	30	23	4	2												65	64	129
100~149		2	17		8	4	1	1									46	20	66
150~199		1	1	6	8	1	1										18	16	34
200~249				1	2	2	1	2									8	7	15
250~299						3	1	1		1						1	7	2	9
300~349					1		3	2	2			1					9	2	11
350~399								5		2	2		1				10	1	11
400~449										1	1	1	1			1	5	1	6
450~499									2	1	1						4	1	5
500~599												1	1				2	1	3
600~699												1				2	3		3
700~799															1		1		1
800~899											1						1		1
900~999																			
1000~																1	1		1
Sub total	82	66	47	26	21	10	7	11	4	5	5	4	3		1	5	297	230	527
New Entry	182	125	40	17	12	8	4	7	1		2	2	1				401		
Total	264	191	87	43	33	18	11	13	5	5	7	6	4		1	5	698		

Source: The Department of Agriculture and Commerce, *Zenkoku Seishi Kojo Chyosa Hyo* (*Survey of Silk Reeling Factories in All Japan*)

Note: 1) As the measure of scale, the number of reeling basins is used.

2) "Withdrawal" includes the factories whose scale dropped to less than ten reeling basins.

first filial generation. This is a typical case in which the improvement of intermediate goods augmented the output without a corresponding quantity or quality change in capital and labor.

With regard to *Zakuri* silk, it should be noted that the *Zakuri* apparatus did not remain as they had been, but were partly improved under the technical stimulus introduced from Europe. They increased the number of cogwheels for smoother operation, and adopted the Kennel system for better binding of the filaments. The share of the primitive *Zakuri* silk in Japan's silk exports sharply dropped from 81 per cent to 2 per cent during the years 1875 to 1895, while the improved *Zakuri* silk grew from 5 per cent to 22 per cent for the same period. The change in the relative position was due to the technical superiority of the improved *Zakuri* apparatus, which could produce finer raw silk suited to the foreign demands.

The entrance into the raw silk industry can safely be assumed to be almost completely free. *The Survey of Silk Reeling Factories in All Japan* gives the data on the name of factory, its proprietor, and the date of establishment, on the base of which we are able to make a transition matrix of factories by scale.[3] Table 1 shows the transition matrix for Nagano Prefecture, the production center of Japanese silk industry between 1911 and 1918. The number of filatures in 1911 was 527, of which 297 factories were still in business in 1918 and the remaining 230 factories had gone out of business. The number of reeling factories in 1918 (698) is the sum of the surviving factories (297) and those which were newly established during these seven years (401).

There were many factories which withdrew from the indstry, however more factories entered into it. The entrance and withdrawal can be observed among large scale factories as well as among small scale ones. This enables us to characterize the raw silk industry as being fairly competitive. Competition is, on the one hand, often accompanied with the waste of capital equipments due to bankruptcy. But on the other hand it should be appraised as a motivational power of growth. Competition among silk manufacturers induced their desperate efforts for survival and gave rise to a great number of innovations. The entrepreneurs paid close attention to every part of the reeling process, in order to reel more silk from the given amount of cocoons, to raise the output per hour, and to improve the quality of the product. Therefore, we may say that many kinds of devices listed above are the results which competition brought about.

II. *Borrowed Technology in Raw Silk Industry*

It is widely accepted that borrowed technology is one of the primary factors which ensures a high rate of industrial growth in developing countries.[4] Industrialization of the Japanese economy owes very much to the advanced technology borrowed from the West. This explains one of the reasons why Japan could attain such a high speed of economic development.

There seems to be two typical cases in borrowed technology. The first type is the case where the developing countries import without any important modifications the capital in-

[3] We used the number of reeling basins as the measure of scale.

[4] The term "borrowed technology" was emphasized by A. Gerschenkron in his book, *Economic Backwardness in Historical Perspective*, 1962.

tensive method of production developed by the advanced countries. Several machine filatures in the early Meiji period relied on this type of borrowed technology for their production. The reeling equipments made of iron which were used in the factories built at Maebashi and Tomioka, were imported from abroad. The imported equipments were elaborately manufactured and effective in reeling, but they were more expensive than the traditional wooden ones. Many entrepreneurs realized that it was fallacious to invest a large amount of funds on these expensive equipments, and that it is only when they have to pay much higher wage rates that the capital intensive method of production can be justified. Another factor must be added which deterred the entrepreneurs from using the foreign made equipments. In the early stage of economic development, it was difficult to acquire the materials or parts necessary to repair the imported equipments when they happened to break.

It still holds in the second type of borrowed technology that the advanced technique of production embodied in equipments is introduced from foreign countries. The fundamental difference is that in the second type some modifications are undertaken in order to make the factor proportions congruous with the domestic factor prices. We shall see below a few examples of these modifications.

Reeling equipments used in machine filatures can be classified into three groups by the materials of which they are made; iron reeling equipments, wooden equipments, and wooden equipments whose principal parts are made of iron. The first was imported from Europe, that is not produced in Japan. Table 2 gives the percentage composition of reeling equipments by the materials for machine filatures. Though the table covers only a short period, it shows some important facts. (a) The composition of iron reeling equipments is very small, and that it decreased from 2.6 per cent in 1904 to 0.9 per cent in 1914. This fact means that iron equipments were not widely used in the Japanese reeling factories. (b) The share of wooden equipments dominated the others. The trend found in the table suggests that in the earlier period more wooden equipments might have been used. (c) During the years covered by the table, the transition from wooden equipments to those made of both wood and iron can be observed.

The iron equipments are able to realize higher labor productivity, while the wooden ones often warp because of the dampness inside the filature, so that their reels whirl less smoothly.

TABLE 2. PERCENTAGE COMPOSITION OF REELING EQUIPMENTS BY THEIR MATERIALS

Year	Wood	Wood and Iron	Iron	Total (%)
I Composition of Machine Filatures				
1904	81.7	16.4	1.9	100.0
1910	70.6	27.3	2.1	100.0
1914	57.8	41.6	0.6	100.0
II Composition of Reeling Basins				
1904	77.1	20.3	2.6	100.0
1910	69.7	28.4	1.9	100.0
1914	61.6	37.5	0.9	100.0

Source: See Table 1.

Note: 1) The figures are for machine filatures in six prefectures (Nagano, Gunma, Saitama, Yamanashi, Gifu and Aichi).

2) "Wood and Iron" means wooden equipments whose principal parts are made of iron.

The equipments made of both wood and iron fall between the two. It is apparently inevitable that the change in the materials from iron to wood has an unfavorable influence on reeling efficiency. But, since the equipments made of wood, or of both wood and iron, were of lower prices than the iron ones, there was no discrepancy between the factor proportions and the domestic factor prices. In addition to this, the lower prices of these kinds of equipments mitigated the damage due to economic obsolescence involved in technical progress. The entrepreneurs could replace the old-fashioned machines by the more up-to-date ones with less hesitation and more promptly. This should be counted as one of the factors which raised the rate of technical progress in the raw silk industry.

Moreover, the entrepreneurs changed the source of power for moving machines and the source of heat for boiling cocoons. Table 3 gives the number of machine filatures by the source of power, i.e., water, steam, electricity, or gas, and Table 4 shows the percentage composition of factories by the source of heat. These data also reveal that the manufacturers in the raw silk industry did not adopt the expensive apparatus that would increase the capital intensity. They relied on the traditional source of power, that is watermills, instead of boilers and pistons installed in the foreign made iron equipments, and used charcoal or firewood, not steam, in boiling cocoons.

The type of borrowed technology which was found in the Japanese silk industry seems

TABLE 3. NUMBER OF MACHINE FILATURES BY THE SOURCE OF POWER

Year	Total	Water	Steam	Electricity	Gas
1892	2602	2089	513	—	—
1895	2283	1454	829	—	—
1899	2073	1108	965	—	—
1904	2320	1064	1248	6	2
1907	2385	812	1552	15	6
1910	2491	1001	1435	48	7
1914	2260	693	1345	220	2
1917	2680	706	1322	648	4

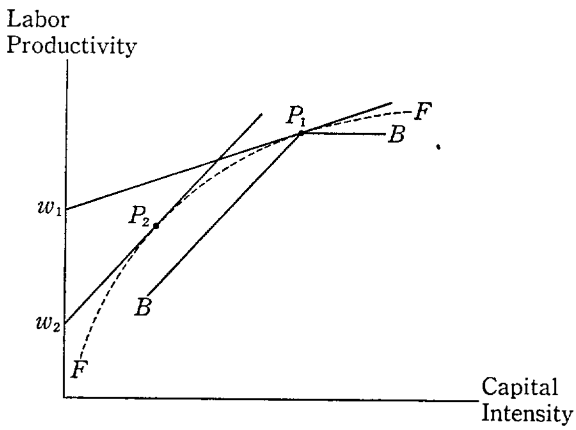
Source: See Table 1.
Note: The Figures are for all prefectures.

TABLE 4. PERCENTAGE COMPOSITION OF REELING FACTORIES BY THE SOURCE OF HEAT FOR BOILING COCOONS

Year	Steam	Charcoal or Firewood	Electricity	Total (%)
1892	36.7	63.3	—	100.0
1895	52.9	47.1	—	100.0
1899	60.4	39.6	—	100.0
1904	60.7	39.3	—	100.0
1907	67.6	32.4	—	100.0
1910	69.2	30.8	—	100.0
1914	78.8	21.2	—	100.0
1917	94.7	4.4	0.9	100.0

Source: See Table 1.
Note: The figures are for all reeling factories in Japan. Therefore, *Zakuri* silk and dupion silk reeling factories are included.

FIGURE 2. TYPES OF BORROWED TECHNOLOGY



to be attributable to a narrow gap in reeling technique between Japan and Europe in the early Meiji period. It cannot be denied that there was an appreciable difference between *Zakuri* reeling inherited from the prior age and the Western machine reeling, but the technical gap must have been much narrower as compared with that which the present-day developing countries experience when they come into contact with an automatic spinning machine, a highly mechanized loom, and so forth. This is the reason why the Japanese silk manufacturers could catch up with and digest the advanced reeling technique within a short period of time. They examined the imported equipments to acquire new technological knowledge, of which some were immediately applied and the others were either reserved for a later occasion or discarded.

In Figure 2, the dotted line, F, shows a production function for an advanced country. If there is no borrowed technology, a production function for a developing country which is lacking in originality or, like Japan before the Meiji Restoration, under a national isolation policy, will lie below that for the advanced country. The production function, *F*, involves a number of potential methods of production whose details are not sufficiently elaborated. Let the wage rate in the advanced country be w_1. The entrepreneurs choose a method of production, P_1, and develop it to practical use. Thus it takes on a concrete form of a completed equipment. It is from this equipment that the developing country learns the most up-to-date technological knowledge.

If the constitution of the function, *F*, presupposes an advanced knowledge of natural science far beyond the developing country, and the development of a particular method of production requires a great amount of money, it will be virtually impossible for the developing country to make its own equipment reflecting the domestic factor prices along the production function *F*. The best and only way which it can share in the benefit of advanced technology is to import the completed equipment in an original form from abroad, even though it is incongruous with the factor prices. This is the first type of borrowed technology mentioned above.

Suppose that an advanced country develops a production method P_1 in Figure 2 and a developing country imports it. Then the production function for the developing country will take a form of a bold line B, kinked at the point P_1, where there is no room for factor substitution. Judging from the production function F, and the wage rate prevailing in the developing country w_2, it should adopt a less capital intensive method of production. A lack of funds and scientific knowledge, however, prevents it from choosing the method which ensures the maximum rate of profit and developing it to practical use. The rigidity of factor proportions and their incongruity with the domestic factor prices are the distinctive features of the first type of borrowed technology.[5]

In the case of the second type, a developing country is able to approach the same body of technological knowledge that an advanced country has, because the technical gap is narrow between the two countries. The developing country develops by itself the other part of the production function F, by applying the new technological knowledge acquired from foreign made equipment. The production function is the same for both developed and developing countries, but a less capital intensive method of production P_2, is chosen in the developing country. As is shown in our figure, a higher rate of profit is realized than in the case of the first type of borrowed technology.

Which type of borrowed technology prevails depends on the industrial structure of technology-importing country and the market structure of technology-exporting country. (i) It was due to a narrow gap between traditional and imported technologies in the early Meiji period that the second type of borrowed technology dominated in the Japanese raw silk industry. In the heavy industry, however, the first type must be observed because of a wide gap of technological knowledge. (ii) In the industry where production methods with different degrees of capital intensity are developed by various sizes of firms in the advanced country, we have the third type of borrowed technology. In this case, developing countries are able to choose the most fitted technique from among a variety of production methods. However, in the monopolized industry, only one production method is realized. If a big technological gap exists, there is no choice but the first type of borrowed technology for developing countries.

III. *The Rate of Technical Progress in the Silk Industry*

In this last section, a tentative estimate of the rate of technical progress will be given. Let the silk output be Q, the capital stock K, the number of female operatives L, the amount of cocoons used M. All these variables are for the machine filatures. The production function for the Hicks-neutral technical progress is,

$$(1)\quad Q=A(t)F(K,L,M)$$

which function is assumed to be homogeneous of degree one. Let $dx/dt \cdot 1/x=G(x)$. Then we get

$$(2)\quad G(Q)=G(A)+\alpha G(K)+\beta G(L)+\gamma G(M)$$

[5] This is what R.S. Eckaus insisted in his article, "The Factor-Proportions Problem in Underdeveloped Areas," *American Economic Review*, Sept. 1955.

TABLE 5. THE RATE OF TECHNICAL PROGRESS IN MACHINE FILATURES
(Five-Year Rate of Change)

	$G(Q/L)$ (1)	α (2)	$G(K/L)$ (3)	γ (4)	$G(M/L)$ (5)	$G(A)$ (6)
1901~1905	16.9%	0.259	7.9%	0.660	9.1%	8.8%
1906~1910	26.4	0.192	8.2	0.721	24.2	7.4
1911~1915	26.2	0.070	7.6	0.829	28.3	2.2
1916~1920	26.1	0.067	9.6	0.836	20.3	8.5
1921~1925	34.3	0.073	4.6	0.816	28.2	11.0
1926~1930	12.1	0.048	13.2	0.828	4.4	7.8
1931~1935	50.9	0.057	25.3	0.818	26.4	27.9

Note: 1) The figures in columns (1) to (5) are estimates by the author. See note for Figure 1.
2) $G(Q/L)$, $G(K/L)$, and $G(M/L)$ are five-year rates of change calculated from five-year averages.
3) α and γ are five-year averages for the respective periods.

where α, β, and γ are the elasticities of silk output with respect to capital, labor and materials respectively. Since we assume that the prices of factors are equal to their marginal productivities, these parameters are equivalent to the relative shares of profit, wage bill, and material cost in the value output of silk. $\alpha+\beta+\gamma=1$, so that equation (2) can be rewritten

$$(3) \quad G(Q/L)=G(A)+\alpha G(K/L)+\gamma G(M/L)$$

from which we can calculate $G(A)$.

Table 5 gives the data necessary to measure the ra'e of technical progress by using equation (3). The columns for $G(Q/L)$, $G(K/L)$, $G(M/L)$, and $G(A)$ show the five-year rates of change calculated from the five-year averages, and α and γ are the five-year averages for the respective periods.

From column (6), the changes in the rate of technical progress can be observed. 1921–25 and 1931–35 are the periods when the rate of progress was relatively high. In the latter half of 1910's, there occurred various kinds of innovations such as improvement of the quality of cocoons, progress in the method of boiling, and division of labor, and it was in the years 1921–25 that these innovations had a perceptible influence on labor productivity. The highest rate of technical progress during 1931–35 seems to have been due to some automatic apparatus, for instance, for finding a filament end or jointing it to the thread. With the increase in reels per basin, the enterpreneurs felt the more urgent necessity of automatic operations. Though entirely automatic reeling machines had not yet been completed in the prewar period, the entrepreneurs began to introduce the automatic apparatus into some steps of reeling process.

Small innovations, if they take place frequently, will have a remarkable effect on the long run trend of labor productivity. They should also be appraised in helping the developing countries to cultivate their own originalities, for small devices are much easier to make than spectacular innovations. But it should be added that I have no intention to generalize the conclusions drawn from the raw silk industry. In some industries there may be only a limited room for small innovations. Especially as for the types of borrowed technology, they must vary from industry to industry. It is because the technological gap was narrow between Japan and the West that the second type dominated in the silk industry.

HITOTSUBASHI UNIVERSITY